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Abstract

Robert M. Gagne, Ralph W. Tyler, and Wilbert J. McKeachie, in independently prepared statements made before a summer institute on effective teaching, emphasized that good learning is active rather than passive; stresses the learning of principles; exploits the advantages in newness: exploration of something new, a new practice, a principle learned in a new situation; requires the learner to set high but attainable standards of performance for himself; and is met, in sum, in guided discovery, problem-oriented instruction, or inquiry. Practical implications for college teaching are that (1) exposition and the transmission of fact be minimized, that lectures take the form of one-sided conferences in which the lecturer raises and analyzes problems and orders, augments, and examines the facts acquired by the students through their own reading; (2) instructors not give direction to be followed in the laboratory but allow students to make the observations or do the experiments necessary to get the data required by the problem, that the laboratory be made experimental; (3) in group conferences the students discuss problems, identify the relevant facts and ideas, and fashion their own hypotheses or conclusions under faculty direction; and (4) examinations be used to help students discover how well they understand the subject under discussion and how well they use the methods required in reaching these understandings. (Author/JS)

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NEW DIMENSIONS in Higher Education

Approach to Teaching

by

Winslow R. Hatch
Specialist, Higher Education

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
John W. Gardner, *Secretary*
Office of Education
Harold Howe II, *Commissioner*

New Dimensions in Higher Education

THE SERIES "New Dimensions in Higher Education" deals with developments of significance to colleges and universities and is addressed to all persons interested in improving the quality of higher education. Each number is intended, within the bounds of reasonable brevity, to provide the harried reader with a summary and interpretation of a substantial body of information. Background information was obtained from reports of published literature in the field in the Educational Research Information Center (ERIC) and from educators who are recognized authorities in the subjects treated.

A listing of the numbers in the series appears inside the back cover.

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Foreword

WHILE THE AMERICAN COLLEGE STUDENT is probably better housed today than was a college student 50 or even 10 years ago, it is not at all clear that he is better taught. It is disturbing to note the frequency with which administrators observe that they do not know how to recognize good teaching and good teachers. Even more disturbing is the way their audiences nod in assent. Whether the administrator does not know what good teaching is, or does not know who his good teachers are, is not clear. In either event, it is a damaging revelation. Whether the problem is presumed or real, it clearly needs to be examined.

The larger theses the reader might examine are that good learning, and hence good teaching, is identifiable; that this being true, it should be possible to recognize good teachers; that if good teachers are recognizable but go unrewarded, good teaching is honored in the breach.

THOMAS CLEMENS
Officer in Charge
Research Branch

Contents

The Problem

THE THESIS EXAMINED IN THIS STUDY is that the *approach to teaching* should be systematic, critical, and deliberate. The study examines the question raised by thoughtful teachers as to whether they are, in fact, teaching. They could be instructing or informing to a degree that is good neither for them nor their students. Research has demonstrated that students can acquire information as well without the personal intercession of an instructor as they can with it.[1] Since teaching machines appear to inform students as effectively as some instructors do, and since television can inform more students than a teacher can in a conventional classroom situation, professors are bound to wonder about the desirability of teaching that is primarily or even exclusively informational. The question becomes still more pointed when the learning specialist tells us that "the first thing a teacher should know about teaching is to know enough not to teach"[2] in the sense of informing or telling.

Teaching, as the word is used in this publication, is what is left after a teacher stops transmitting information. It involves the teacher's and the student's examination of the information that the students have acquired, preferably through a substantial effort on their part. There is, of course, little excuse for teachers to be uncertain about their true role because learning specialists have been describing it for years: It is to direct student learning.

What this means should pose no problem because students learn in much the same way as do their teachers. The teacher typically calls his learning *research* or *inquiry*. *Inquiry* would, accordingly, appear to be

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[1] The Committee on Utilization of College Teaching Resources, *Better Utilization of College Teaching Resources*. New York: The Fund for the Advancement of Education, May 1959, 63 p.

Allan O. Pfnister. "Review of Research on Class Size," *The Annual Conference on Higher Education*, University of Michigan. N[illegible] 17-18, 1959, pp. 17-26.

Samuel Baskin. "Quest for Quality," *New Dimensions in Higher Education*, No. 7. Washington: U.S. Government Printing Office, 1962, 18 p.

Thomas S. Parsons, Warren A. Ketcham, and Leslie R. Beach, "Effects of Varying Degrees of Student Interaction and Student-Teacher Contact in College Courses." Ann Arbor, Mich.: School of Education, University of Michigan, 1958, 56 p. (Processed).

Winslow R. Hatch and Ann Bennet. "Independent Study," *New Dimensions in Higher Education*, No. 1. Washington: U.S. Government Printing Office, 1960, 36 p.

[2] Robert M. Gagné, "Principles of Learning," *Achieve Learning Objectives*. University Park, Pa.: The Pennsylvania State University, 1963. A report of the Summer Institute on Effective Teaching for Young Engineering Teachers, Aug. 25-Sept. 7, 1963, Otis E. Lancaster, Director.

a good word to describe a teacher's teaching and the learning of his students.

The problem of providing more good teaching and more good teachers—as defined above—is obviously not going to be met merely by recruiting more instructors (meaning purveyors of information), paying them more, or improving the conditions of their employment. Although these things must also be done, the problem can only be met by preparing more and better *teachers* and converting as many instructors as possible into teachers.

This study, it is hoped, will help teachers to determine whether they are teachers or instructors, or the degree to which they are one or the other. It may also suggest how an instructor may become a teacher, or at least how he may become a teacher for a greater part of the time.

The Evidence

SINCE THE MEASURE OF TEACHING is the quality and quantity of learning that takes place, any inquiry into teaching must deal with the conditions of learning. It would, of course, be desirable to have a consensus as to what constitutes good learning, a consensus that reflects the judgment of persons who have done research on this subject and are able to appraise the considerable literature that attracts but dismays teachers who lack this competence. Although no consensus was available, it was possible to develop one from the following three papers: "Principles of Learning" by Robert M. Gagné, formerly Professor of Psychology, Princeton University and now with the American Institute of Research; "Conducting Classes To Optimize Learning" by Ralph W. Tyler, Director, Center for Advanced Studies in the Behavioral Sciences, Stanford University; and "Recitation and Discussion" by Wilbert J. McKeachie, Professor of Psychology, University of Michigan.[3] The consensus that emerged, quite apart from its substantive merit, is recommended by its brevity, the creditability of its witnesses, and by the fact that it was arrived at independently. The points emphasized by Gagné, Tyler, and McKeachie, stated as succinctly as possible, are:

Good conditions of learning are met when:

a. "The human learner . . . is made the central part of education as a system." (Gagné)

b. The learning reflects that which "the learner learns," that is, that which "he is thinking, feeling, or doing." (Tyler)

c. The learning is "active" rather than "passive." (McKeachie)

d. "The learning situation encourages 'generalizability,' the learning of principles, as opposed to . . . rote learning." (Gagné)

e. A "principle" is learned "in a new situation." This helps one to "identify the common element in situations and shortens the learning process." (McKeachie)

f. A student "explores something new." (Gagné)

[3] *Achieve Learning Objectives*, Otis E. Lancaster, editor. University Park, Pa.: Pennsylvania State University, 1963.

g. "Each new practice requires him to give attention to it because of new elements in it . . . [only so] does it serve adequately as a basis for effective learning." (Tyler)

h. Importance is attached to "levels of aspiration." (Gagné)

i. The learner "sets high standards of performance for himself . . . high but attainable." (Tyler)

j. "We can teach students to enjoy learning." (McKeachie)

Endorsed were:

a. "Guided discovery." (Gagné)
b. "Problem-solving." (Tyler)
c. "Problem-oriented instruction . . . Experience in solving problems within the students' ken is essential." (McKeachie)

The Working Hypotheses

WHAT WOULD A CRITICAL READER or teacher have to do to test the principles and conditions described by Gagné, Tyler, and McKeachie? He would have to examine them, develop working hypotheses, and design an experiment and classroom situation in which all of the hypotheses were tested one by one, and all together. Why all and why all together? Because were just one hypothesis proven untenable, it might affect others and thus invalidate the whole experiment. If one has an equation with many factors in it, he must, if he is to have any confidence in his results, include all factors.

There are, of course, several ways of examining the hypotheses. One could, for example, farm out the experimentation to several individuals. This would not be satisfactory because, as has been noted, the test of any one is affected by the others. One must, rather, try to accommodate all of the hyphotheses in an overall experiment. But how? Should every item be examined, each in turn, for its implications for the practicing teacher? No, this would not be very helpful, because the problems met in the classroom do not present themselves one at a time. One might rather approach the experiment as a new course assignment is approached, by asking what the teacher does during the summer or with whatever time for preparation he has? What does he do a week before or the night before the first lecture? What would he do during the first meeting? In the first minute?

Before such a study is attempted, let us examine the circumstances which might cause a teacher to consider a new or experimental approach to his teaching. It might be an administrative request. Under these circumstances, the teacher has little choice. Or it may be that the teacher has had some trouble with his self-respect, from which Galsworthy tells us there is no escape. It may be that nothing very important has happened to the students in his classes. They have gone through the motions, may even have made good grades, but they may not have found the instructor or the subject very exciting. The instructor knows that there is such a thing as intellectual excitement, but his enthusiasm for and commitment to his subject is not caught. The teacher's conclusion may be that there must be a better way than that which he has employed; that if there is not, there must be a better way of making a living than by teaching. He may have no idea of what he wants to do, except that it is different from what he has been doing. Irrespective of his motivation, let us design an experiment and elaborate the test to the point where there can be no question as to its validity.

Implications for Content

What should one teach? Should the instructor take the first hurdle—the first lecture—in a fine burst of speed, and then start talking about motivation, reinforcement, and the other factors that affect teaching? He can hardly do this because he has to teach something, and this must be resolved first. The first question, then, would appear to be, *What* is to be taught?—that which was taught?—that which someone else has taught?—that which the textbook covers?

None of these would seem to be entirely satisfactory. How, then, might the instructor answer this question more satisfactorily, trying always to be critical and hopefully scientific?

It would be helpful if he had criteria as to what should be included and what should be excluded. But where is the instructor to look for such criteria? What about the principles of the subject matter in question? While this raises the question as to what is meant by a principle, and while this is easier for a scientist to answer than for teachers of the social sciences and humanities, it is not easy even for the scientist. He has only to ask his colleagues to find that he is likely to get about as many answers as he has colleagues. What he would like to have are principles about which there is more general agreement and to which there is explicit reference in the literature. These conditions are met in the theories and hypotheses of the subject. Were he to act on this counsel, he would still not be out of the woods, because he still has to decide which principles, which theories, and which hypotheses—for there are always more than one—he can "cover." Why not concentrate on the major ones, the most inclusive ones? Or, working from the other end, why not eliminate those that are most expendable?

The next step is easier: to settle upon that which constitutes the minimal number of facts which are required to discover the principle. In addition to the advantages in discovery extolled by Jerome Bruner and Gagné, this approach has the advantage that it requires more facts than the ones students are usually expected to acquire.

Once the above problems have been resolved, the instructor can plan the course so that the factual material needed is examined in appropriate lectures and conferences and put to use in the laboratory. The technique of shifting the contexts in which the material is discussed is, of course, a useful one.

Now that the *what* has been disposed of, one can examine the problem of *how* to improve the teaching.

Implications for Method

How should one teach? Any teacher can make these determinations for himself; but before he would be able to examine all the implications in the conditions of learning treated herein, he would have to give more time to it than may be available to him. Since it takes no great mental acuity to do this—the major problem being time—let us examine an experiment that fits and orders the evident pieces and tests the several hypotheses, being concerned only with traditional operations—lectures, laboratories, conferences, and examinations.

Since Gagné finds guided discovery to be an effective learning device, and since Tyler and McKeachie recommend problem-oriented approaches to teaching, methods in which discovery or inquiry is accommodated should be exploited.

If the implcations in the conditions of learning are to be identified and tested in any complete fashion, one needs to examine them first for his lectures and then for the laboratories, conferences, and examinations.

The Lecture—A lecturer cannot employ the same kind of presentation day after day and meet the requirements of the subject or of the students. It can be expository under some conditions; it should never be expository under others. Before the lecturer finally decides what he proposes to do, he should examine the uses to which lectures are put. Of the expository lecture one must ask whether its general use is justifiable when teachers are in short supply but books, mimeographed materials, teaching tapes and film can be mass-produced.

Even when lectures *illuminate* rather than *follow* a textbook, one must ask whether the material might not be *better* illuminated for the students by getting them to intend their minds upon it.

Lectures are also used, on occasion, to describe the method appropriate to the discipline in question. These lectures may be on the scientific method, the historical method, the art of good writing, or on how to study—or even on how to study independently. But here, if anything has been learned, it is that one learns a method—not by hearing about it, reading about it, or by talking about it—but by using it. The method in question should be used by the students *and* the instructor, not just during the lecture in which it is described, but throughout the course. Disturbing is the fact that few lecturers use a critical method in discussing it.

Even when lectures are interpretive and the lecturer seeks to show the significance of the material in question, he can fail because that which is important to the lecturer may not appear important to the students because they were not permitted to discover its significance.

One reason for giving so much attention to the lecture is the fact that provision will almost certainly have to be made for more large classes in the future, and that only lectures can be employed under these circumstances. While large class presentations may have to be made, they do not necessarily have to be expository. If 450 students constitute a large class, it has been demonstrated—and over a 10-year period—that conference-like, even Socratic, lectures are practicable and effective. While the expository lecture must sometimes be employed because students are so indifferent or capable only of listening and of regurgitating, nothing is better contrived to perpetuate indifferent scholarship than the expository lecture.

The vehicle most frequently used in televised presentations is the expository lecture. The justification given is that it makes good teachers and good teaching go farther. A disturbing aspect of the use of such lectures is that they may be an excuse for not doing something better but more difficult, namely, to examine the materials under discussion and to provoke discovery or inquiry.

If it is assumed that a Socratic lecture, for example, is dislocated and aimless, hence unsatisfactory, the assumption should be reexamined because a good Socratic lecture is tightly organized and is efficient as well as effective. Neither is it lacking in drama. Actually, it has more of this quality than the expository lecture, because it involves the listener and hence exploits the essence of good "showmanship." Finally, the Socratic lecture has spontaneity and carries conviction because of its spontaneity.

In his preparation, the lecturer will assemble the facts bearing on several alternative presentations and weigh their advantages. He will, however, take his lead from the students, when practicable, by beginning his lecture with a carefully framed question. He does this, in part, because he wants to involve his students even in his lecturing. Of the different ways of developing the lecture, the best one is usually the one that the students suggest by their answers. Their responses often have to be rephrased because they concern material too involved for them, or unavailable to them, or they require equipment or skills they do not have.

Some of the questions the lecturer asks himself in planning his lectures are: (1) What facts can the students get in sources available to them? (2) What additional facts will have to be supplied if the students are to have all they need? (3) What role does the teacher want his students to play in the lecture? Are they to be merely "note-takers"? If so, all that the teacher is likely to see of them is the tops of their heads. If the students are provided with transcripts of the lectures, they do not need to take so many notes.

Rather than to encourage note-taking, the lecturer may want the students to think along with him. By pressing them to the point where they ask questions he can often involve them from the opening moments. When sufficient interest forms about one of the student's questions, the lecturer can build it into a problem that is sufficiently substantial and searching enough to sustain the students' interest for the whole lecture, or for several lectures, or for other class meetings. When this is done, the students may be persuaded that the original interest in the subject was theirs and that the choice of the problem was theirs. In examining the problem with the students, the lecturer tries to get them to suggest how the problem might best be attacked. Later when the students are asked to volunteer whatever facts they have gleaned, they may—if their contribution is substantial—conclude, and properly so, that theirs was a substantial contribution to the lecture. If the lecturer is interested in how his students think, his interest will show through and his students will think along with him. They may even follow along closely enough to interrupt him when they lose the direction of the argument or catch him in some irrelevancy.

The best questions raised by the students are likely to be very conspicuous. To have asked them, and to have had them recognized as perceptive, flatters and involves the questioner. Such recognition gives other students a mark to shoot at, and often a disposition to shoot at it because they, too, would like to bask in the high opinion of the teacher and their fellow students. A course taught in this way has a quality and tone that flatters students because it is thoughtful and hence worthy of the best efforts of men and women in an institution of higher learning.

If a critical examination of facts or postulates is brought off in the lecture, students can be counted upon to be attentive. Finally, when the students discover that the most expeditious way of studying for the course is to take their cues from the lecture—both as to the material that is relevant and the method that needs to be used—they will be attentive.

Before the lecturer finally faces his students, he will want to think long and hard about the language, the metaphors, and the illustrations he proposes to use to give his lecture bite and thrust.

One thing the good lecturer will discard is the conceit that he is going to "instruct" his listeners. If he is wise or experienced, he will know that the best he can do is to create the conditions under which his students will *want* to learn and *will* learn.

In the *first lecture* one has an opportunity he never has again to put first things first. These first things are the basic ideas or principles that animate the course. The lecturer will not, of course, identify these principles in advance or by name. He will, rather, identify and describe the phenomenon in question and then literally step back and ask the students whether they can think of anything more important, more interesting, or more appropriate for them to study. If they can come up with nothing better, his next question might well be: How would you propose to learn more about the matter, learn it well, learn it quickly, and perhaps, find a satisfactory explanation or explanations? More than this, they will learn whether they have one of the essential attributes of educated men, namely, the ability to ask the right question. Finally, the students will discover one of the basic reasons that brought them to the course and to an institution of higher learning.

The students' questions can be counted upon to prompt the observation that there appears to be a basic problem in the phenomenon under discussion and that it would be interesting, perhaps profitable, if the class were to consider it. The class may have trouble stating the problem well, but with a prod here and a shove there, an adequate statement can usually be developed by the students. Thus, without knowing it, the students learn how necessary and how natural it is to identify problems.

The degree to which this procedure exploits the task set is very great. Actually, one could ask how this principle might be applied more effectively. One way to exploit the task set and to dramatize it is to write the problem on the blackboard, and to write it on the board at the opening of every lecture, laboratory, and discussion until the problem has been resolved.

The students will soon be wanting some answers, but they must learn to make haste slowly and to discover how essential and expeditious it is to analyze a problem before diving into it. The need to break the problem down into manageable parts and to attack that which is the most manageable is something they are quite capable of discovering.

Students are sometimes astounded (and greatly relieved) to discover that they can determine what it is they are looking for before they start looking—that they can determine what facts are relevant. They can also discover where and how to look for them. In the process of looking, they learn a lot about indices, glossaries, and reference sources and methods. Generally, it is better to let students *discover* this than to *instruct* them in reference techniques. When the students discover that which is relevant to the problem, the lecturer can afford to terminate the lecture. The more abruptly he does it, the better, because it emphasizes the fact that it is the student's responsibility to dig out routine facts.

Students learn a lot on their first solo flight in their efforts at independent study—a lot more than facts. Some learn that they cannot manage such study, that they are not sufficiently disciplined. Some read masses of material rather than scan it, or they memorize it rather than think about it. Some come to the next lecture, hurt and baffled. Some are resentful. This is where the teacher with little faith in himself or his students "blows" the course. Caving in before student pressures, he starts spoon-feeding and attempts the impossible, namely, to do the students' thinking for them. If, instead, he moves serenely ahead, he makes the transition from instructor to teacher.

This approach has the advantage that in assuming a maturity and a disposition to learn—even an ability to learn—it is difficult for students to act irresponsibly. But how, in courses where this approach has been used successfully, are students induced or forced to dig out their own facts? By not giving them the facts, either in lecture, discussion, laboratory, or in answers to direct questions. If they cannot get their facts this way, students will of necessity study the material or look inside a book.

Another way to insure that the students will come to class prepared is to assume this preparation and to plan the next lecture, laboratory, or conference as though this were the case. When students discover that the lapse of just one evening's study wastes their time because they cannot understand what goes on in subsequent meetings, they tend to come prepared. Group psychology can also be exploited. If a student finds himself missing the point and missing the satisfactions his fellow students register, he is likely to mend his ways.

There are several reasons for having the student dig out his own facts. By learning how to use a library, he frees himself from the tyranny of authority—the tyranny of the lecturer, the laboratory, and the textbook; and he actually learns more because he frees the professor to add facts that deepen and broaden his study. When students play this role and play it responsibly, the teacher is better able to apply his scholarship. It is also good for a teacher's self-respect.

While the students are busying themselves trying to anticipate the next lecture, what is the teacher doing? He is trying to anticipate what the students' requirements will be in the upcoming lecture. Since he cannot do this very well before he steps into the classroom, he is better advised to study the requirements of the problem. What facts does he need to resolve it? What new facts appearing in the current literature and not likely to be picked up by students should be presented by him? The subject will, of course, have more appeal if it can be made timely; and, certainly, the nearer the course is brought to the present, the better the student will be able to see the relationship between the artificial situation (the classroom) and the real-life situation outside the classroom. Since the present is as close as the teacher can get to the future for which he is preparing his students, he will try to keep up to date.

One way of handling the lectures in which the students volunteer the facts they have acquired is for the lecturer to assemble on the blackboard (in columns, graphs, or charts) all of the relevant facts the students are able to supply. He then adds his facts. The columns should not be labeled or the coordinates identified. He has a reason for his columns and coordinates, but the students should be given the opportunity of discovering what it is. The lecturer's role is to order the facts so that it is possible for the students to see the associations and relationships that are not immediately apparent. This "chinking" and "charting" is done so that the student has a basis for sound inference. The lecturer can estimate when such a basis has been established because he has determined in advance what facts are essential for the development and testing of a sound hypothesis.

Only by coming prepared to these lectures can the student determine whether he is acquiring some of the answers he needs. The attention shown his contribution by the teacher and his peers reinforces his good intentions. But more than this, and more important than this, is the fact that the student is gratified, not by reason of a correct response that a parrot might make, but by the instructor's assumption that the student has the maturity and the intelligence to hold his own in an inquiry that is real and genuine. If it is contrived, it will fail and deserve to fail.

For a more detailed treatment of the problems met in lecturing and for a demonstration of lectures that exploited the Gagné-Tyler-Mc-Keachie "conditions," an edited transcript of an article, "The Lecture," (which appeared in *Improving College and University Teaching*, Winter 1958 issue), follows.

LECTURE: THE NATURE OF LIFE

One of the wisest men I know once told me that after 30 years of teaching and some 6 or 7 years of retirement, he thought he knew why one goes to college. "One goes to college to learn how to ask questions." How, then, does one learn something about biology? By asking questions. Now about biology, the science of life, what would you like to know?

"What is life?"[4]

That is a good question, almost too good. While we could engage the subject on a broad front, let us try for something that will be more manageable. Let us separate structure from function and examine these two aspects one at a time.

Were we to do this, our first questions might well be, *Does life have a structure? If it does what is it?* But how does one determine whether life has a structure? To answer these questions one must learn a good deal about the structure of living things. But in doing this, and even in advance, it would expedite ou_ study if we knew what it is in all this structure that is relevant to our problem.

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[4] Student responses are quoted in separate, italicized paragraphs.

You know the story of the blind men and the elephant. (Here is read the poem "The Blind Men and the Elephant" by John Godfrey Saxe. Six blind men, approaching the elephant from different directions, felt only parts of the animal. One feeling its side described it "as a wall"; one its tusk, "like a spear"; one its trunk, "like a snake"; one its knee, "like a tree"; one its ear, "very like a fan"; one its tail, "very like a rope.") What does this story suggest as to how we might best proceed?

"We have to have ALL the facts."

All the facts there are on morphology, anatomy, histology, and cytology—that is to say, the structure of better than two million species?

"Oh no. Not in a 3-hour course."

Before we conclude that we do not have enough time, that the problem is too big for us, let us state and restate our problem and see if we cannot find some way of determining what structure is relevant to our inquiry. What are we looking for? We will certainly want to know this before we start looking for it.

You say you don't know enough about the structure of living things to do this. You don't know very much, but you know enough. Let us start with some pretty obvious living things—you and me. What is there about us that identifies us as living entities? Do we have something that makes us alive, something that distinguishes us from the steel girder above our heads? Do we have something that that girder lacks? We have appendages, we have arms and legs, we have a head and torso. Yes, and we have organs, stomachs, intestines, hearts, and brains. But how relevant to this study are appendages and organs?

"Not very, because our analysis must include living things—all of them, not just one or some."

Yes, we must keep in mind that there are living things other than ourselves; that there are the other animals and there are the plants. A survey, however, of the animal and plant kingdom, done well, could take a year. Before we abandon our inquiry for lack of time, let us see if we do not have sufficient common knowledge about animals and plants to see us through.

The structure we are looking for must, of necessity, be found not only in the most elaborate of animals, animals like ourselves, but in very small and very different animals. You may not know very much about the protozoa, the smallest animals, but you have at least heard of the *Amoeba*. The *Amoeba* is of microscopic size; is a single cell; is, as we say, unicellular. While you may not recognize it, you have just acquired some useful information. What is it?

"It is that anything as large and as complex as organs is too large for the purpose of this study."

Very good. What about tissues, the component parts of organs? What of the stomach lining, for example? It is not very substantial, to be sure, but it is large enough to be seen by the unaided eye—it is still macroscopic in size. This and other tissues are made up of cells.

Tissues are "out" too, you say, because an amoeba is microscopic and tissues are macroscopic.

The only structures, then, that are common to animals would appear to be—?

"Microscopic in size, or smaller."

Let us examine this suggestion. Let us think about plants and see if we cannot make the little we know work for us. The most elaborate plants have organs: leaves, stems, and roots. These organs are composed of tissues. The epidermis of a leaf, and the pith in stems and roots are tissue. Plant organs are easily seen by the unaided eye. Tissues can be seen, if not as well, without using a microscope. Plant organs and tissues are macroscopic. Plant tissues are typically composed of cells, and these cells are microscopic in size, as they are in animals.

Let us also consider some of the smaller entities in the plant kingdom, for example, the unicellular green alga, *Chlamydomonas*. The name of this organism is not a household word, but it is a common enough plant. This whole plant is microscopic in size. From this we can conclude, without opening a book, that we must look for and at structures and entities of microscopic size or smaller, that is, of cells or of living material no larger than cells. How can we afford to say this?

"Cells, or structures of this size, are all that all plants and animals have in common."

On the basis of *your* facts, it would appear that living things have a cellular organization, for they seem to exist as single cells or aggregates of cells. But what are *the* facts?

There are certain categories of living things which we call slime molds. In most humid forests, if you look closely enough, you will find, scattered over the forest litter, little splotches of yellow or of pink, purple, or pale green material. These splotches are living things. If you were to study them under a microscope, you would find that the thin, wet, and slimy sheets have a structure. They look like old lace with a webbing which is heavier in some places than in others. But look as hard as you will, you will find no compartmentation of the mass. Since some splotches are as large as the palm of your hand, they are large enough to have cells, as we have been using the word—but they don't.

Now, when we find something which does not fit our "scheme of things," what are we going to do about it? Darwin had a good, if jocular, answer—grind it under your feet and forget about it. This is what we have done in biology, more or less, with this type of organism. But we can hardly forget it, because within perhaps 10 feet of the place where the slime mold was found, there may be a little stream. In that stream—growing on old seeds, twigs, or fruits—you might see, if you looked closely, some white, cottony tufts. These plants are water molds. If you were to place one of the white threads under a microscope and were to study it from one end to the other, you would discover that it is not compartmented, but is one long, open tube. It is not cut up into cells, as you would expect.

Finally, let us take a microscopic look at a bit of our own bodies. Even here we are going to make an unusual discovery, for we are going to find that, by weight, less of us is cellular than is noncellular. If you were to take a fiber out of those muscles of yours and were to have a good look at it, you would discover that these so-called striated muscles are made up of long, blunt-ended cylindrical objects not unlike rolled-oats cartons. These cylindrical objects abut on one another. But they are not subdivided into cells. They are large enough to be constructed of cells, but they are not.

If you were to look at heart muscle, you would find that bits of it draw off into fine branches like this (a diagram is drawn on the board) and run into similar branches from other concentrated masses. While these bits of the heart are constricted in these branches, there are no membrances across them. The heart is, apparently, one continuous mass.

When we take all this into account (the structure of the slime molds, water molds, striated and heart muscles), what does it do to the hypothesis we were toying with, that life has a cellular structure? It puts a pretty serious crimp in it. But we have not wasted our time, because we have learned that we not only do not need to study organography, the structure of organs, or histology, the structure of tissues, or even cytology, if by this we mean cellular structures. That structure we are looking for must be found in organs, tissues, and cells, but it must also be found where life shows no cellular organization. What is more, we have discovered the approximate dimensions of our structure. It must be—?

"Microscopic or smaller in size; cellular structure won't do?

What might? It's so obvious as to be difficult!

"That 'stuff,' that content of cells and of noncells. It's the only thing left which is common to all living things and to all parts of all living things."

We have a word for it. The "stuff," the living content of living things, is protoplasm.

Now, at least, we know where to look. The structure we are looking for, if there is a structure peculiar to living things, must be found in protoplasm, be it organized in cells or not.

Keeping in mind what we are looking for, that structure associated with living things and all of them, it must be clear that it will not help us at all to study and memorize the structure of a generalized cell. A generalized cell is a biological monstrosity. Generalized animal and plant cells will not, then, advance our study either. Actually, the facts we are looking for cannot be found in any series of types shorter than the one on the board. We need this many illustrations to make certain that the facts are presented in such number and kind that they fairly represent the differences in microscopic structure to be found in living things. We shall, accordingly, have to look at the microscopic structure of man, a vertebrate; the *Amoeba* and *Diplodinium*, protozoans; the apple tree, a flowering plant; *Anthoceros*, a liverwort; the green algae *Chlydomonas*, *Coleochaete*, and *Vaucheria;* a blue-green alga or two; the fungus *Allomyces;* several bacteria; a slime mold; the flagellates; and a virus.

It is also our responsibility to assemble *our* facts, both those you can supply and those that are known to me. Our final responsibility is to order our facts so as to improve our chances of making sound generalizations. I will not make them for you because I want you to know the joy of discovery, a satisfaction we professors do not always share with our students. All we are saying is that even in lectures students can make discoveries.

It is now your move. You have some facts; you can dig out others. We shall assemble and order them in subsequent lectures, examine them in discussions, and test our ideas and methods in the laboratory. This is all being done to help you shape some hypotheses, some tentative conclusions about the structure of living things. *Does life have a structure? If so, what is it?* You will need to be critical and you had better be explicit and as complete as possible in developing your proofs. *What is the approximate size of the critical elements, their chemical nature, and how are they organized?*

I will throw questions like this at you until the air is blue with them, but I do not propose to answer them because I do not like to steal from my students. Doing your thinking for you is worse than taking your money because it adds insult to injury.

Now that you know *what* you are looking for you can, and should, start looking, and this as soon as possible. Now that you know *how* to look, I should get out of your way. Beginning now, you are about to come of age; you are about to become a student; and you are about to make this a university, so far at least as you are concerned because for you it becomes a "place of inquiry." Good luck and good hunting. Class dismissed.

(The hypothesis ultimately developed by the students is one known to biologists as the Protein Molecular Network hypothesis. Other explanations or hypotheses will, of course, be advanced and found wanting. In the framing of this hypothesis, the students will have closed in on the DNA molecule and the newer research on it, which constitutes a veritable biological breakthrough.)

The Laboratory—In a laboratory that is taught scientifically, a manual of instruction is not needed. Actually, the authority implicit in a manual should be avoided. What is required are problems that the students can attack experimentally. Since there are few models, the instructor's ingenuity is taxed. When the method of instruction in a course is problem-oriented, and involves discovery or inquiry, the laboratory becomes very important and becomes experimental. Precisely what does an instructor do in such a laboratory? He announces the problem or problems which have been anticipated in the lecture and will be followed up in the conference. The students are then turned loose to observe, or test, or experiment, depending upon the students' perception of what is required by the problem.

If worksheets are turned in at the end of each laboratory session, they can be used to help the student discover what he can and cannot do, how many ideas are his, how many still belong to the teacher, and how well he thinks. They also enable the instructor to determine how well he is teaching.

The laboratory is anticipated in lecture and in out-of-class study because the students have been advised to get their facts straight before they come to the laboratory, and to think about the problem to the point where they can anticipate some of the analytical skills they will have to use. They have been told that in the laboratory they will have to think in ways analagous to those employed in driving a car; that to get their study in gear they must develop a sense of Problem or *P*; that the next position on the gearshift panel is *A* or Analysis; and the next, *O* or Observation. This latter, the students are told, is the gear they will use most. An explanation of what they observe, however, will require interpretation; and this position on the panel is identified as *H* or Hypothesis. Finally, the students are urged to throw their study into overdrive, into *CH* or Check Hypothesis.

After the problem has been written on the blackboard, the students are "given their heads." Their role is to look at or do whatever their analysis of the problem suggests. When the students have completed their observations or experiments, the instructor characteristically faces them with questions such as, "What were you looking for?" "Why did you do what you did?" If more than one response is made (and more are always sought), the class is asked to evaluate the several alternatives. The last question, usually directed to one of the better students, is, "What leads you to think you made the right observations or got the correct readings?" When the response is that it was "checked," the class will usually want to know "how?" and the students who understand the problem and have the requisite skills instruct the others. The instructor often anticipates the end of the laboratory by raising a final question, "What bearing does *your* discovery have upon the problem identified in the lecture—the problem we have considered during the past 3 weeks?" In such a laboratory the instructor's role, while not as obtrusive as that of many laboratory assistants, is obviously a significant one.

In advance of the laboratory, the staff prepares a list of questions so pyramided that the stı lent is forced to go deeper and deeper into his problem until he can see some of the implications in his observed facts. In the first laboratory the most important thing the student learns is that, given a problem and materials, he is lost if he does not first analyze it. He has to know what to look for before he starts looking. The analysis expected in the first laboratory is that a category of organisms is identified by whatever the organisms have in common. Since this type of analysis was made in lecture the laboratory is a test of how well the student is able to apply his theoretical knowledge when faced with living things in a real-life situation.

For a more detailed treatment of problems met in laboratory instruction and for a demonstration of how laboratories can be made more experimental, the following edited transcript of the article, "The Laboratory," is offered. This article appeared in the Spring, 1958, issue of *Improving College and University Teaching.*

Laboratory: Green Plants

(Materials in this laboratory were arranged on three tables. Table 1 displayed representative flowering plants and parts thereof: Poinsettia *for floral bracts; a rosaceous plant for a complete flower; begonias for unisexual flowers; a lilaceous plant; a composite flower; a grass flower; male and female willow catkins, with individual florets under dissecting microscopes; sweet pea flowers, pea pods, and soaked pea seeds; an asparagus plant, essentially leafless; mistletoe, seemingly rootless; duckweed, seemingly stemless;* Ricinus; *and skunk cabbage seeds. Beside each plant or part, information was sometimes supplies when it seemed necessary. Table 2 contained representative gymnosperms: branches, dissected male and female cones, and soaked pinion pine seeds. Table 3 displayed* Psilotum, *the ferns and fern allies. Living plants and stages in the life cycle of a fern were assembled here. Again, cards were placed beside the materials when interpretive drawings were required.)*

For this laboratory we have assembled on table 1 representative angiosperms; on table 2, representative gynosperms; and on table 3, representative members of groups we can identify as *Psilotum* and allies, the ferns and the fern allies. On the small benches at the back and at the side of the room are batteries of dissecting microscopes and razors. In case you want to make dissections of anything, slides and coverslips have been provided.

9:00 a.m. The initial problem this morning is, What is an angiosperm? That is all, up and at it. You have 20 minutes.

9:20 a.m. Jones. What do you have for us by way of information that might be helpful?

"Nothing, and frankly, I don't know what you want."[5]

It is not so much what *I* want—it is what the problem requires and specifically what this problem requires of you. Smith, what is an angiosperm?

"An angiosperm, I would guess, is any plant that has a flower."

Does anybody have any other answer he would like to volunteer?

"Well, I don't know, but the literal interpretation of the word angiosperm means enclosed seed. How will that do?"

It will do well enough if I did not think you had gotten that answer straight out of the textbook. What do you mean by enclosed seed? What encloses the seed?

9:22 a.m. We want a careful devastatingly complete answer. We want to be really convincing; so let us dig a little deeper. What did you mean, Smith, when you suggested a flower? Why does a flower seem convincing? Take 3 minutes.

9:25 a.m. If you have indicated that flowering plants or angiosperms or any category of things may be identified by what they have in common, this much of your analysis is correct. If you think angiosperms are plants that possess flowers, you can, of course, draw and label the flowers of a willow, or a dandelion, or a poinsettia. If you have not done so, this is the time to do it. Take another 25 minutes.

9:50 a.m. Your drawing should look something like this. Run through these diagrams tonight and make certain you understand what the essential elements in a flower are. Now that you have looked at flowers a little more critically, perhaps you would like to attempt another summary statement.

"While angiosperms have flowers in common, all of the flower that is common is a pistil and/or a stamen or stamens."

If you have the substance of this in your statement—and be sure you have "and/or" —you are in good shape.

But have you asked yourself what a pistil is? A pistil did not just happen one fine morning and march itself in here with a label dangling from it.

10:00 a.m. In the demonstration materials before you are two mutually supporting lines of evidence as to the origin and nature of the pistil. Take 10.

10:10 a.m. What do you have, Brown?

"I haven't got anything."

Sarah, what do you have?

"The pistil in the sweet pea flower under the dissecting microscope looks very much like the pea pod lying beside it. When opened and stretched flat, it looks like a leaf. A pistil may, perhaps, be a modified leaf because the pod has a midrib and veining in it very much like a leaf."

Good girl. If the rest of you have anything like that you are on target. But suppose someone replies, somewhat disrespectfully, "So what?" What is the significance of a pistil? How would you answer this question, Jim?

"Well, it holds the seeds."

But, Sorenson, what is a seed?

"Some seeds have endosperm, but not all. Some have seed coats, but not all. They all seem to have embryos. I would guess that a seed is a structure that possesses an embryo."

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[5] Student responses are italicized.

Did you follow that? Give it to us again, slowly.

Now, what advantage to a plant do you see in its ability to so dispose its seeds? To get at this it might be well for you to compare seeds as you find them in angiosperms with a spore, another reproductive structure. A spore, and its place in the life cycle of a fern, is shown in the fern exhibit on table 3. You have 8 minutes.

Laboratory: The Life Cycles of Green Plants

Prior to this laboratory a careful study is made of the phenomena involved in a life cycle. This is done in lectures, conferences, and out-of-class study. In an illustration drawn from the fungi, the students are shown how a life cycle can be pieced together from living and preserved materials and from preparations, if one but understands what goes on in a life cycle. The fungus chosen has a very different life cycle from anything discussed up to this point. It is also different from the forms to which the students will be exposed in the laboratory. In sum, the students have to discover these life cycles.

The materials assembled were presented in sufficient detail that the students could construct, illustrate, and label complete life cycles, in this case, of *Polytrichum,* the fern, *Anthoceros,* a liverwort, *Coleochaete,* a green alga, and *Phormidium,* a blue-green alga.

A sample of the problems addressed in this laboratory were as follows:

1. Draw the blue-green alga phormidium and use whichever of the following seem appropriate as labels: spore, gametophyte, male and female gametangia, male and female gametes, zygote, sporophyte, sporangium.
2. Indicate why you chose the terms you did.
3. Under the words *spore, gametophyte,* and so forth, stretched across the top of two sheets of paper, indicate why you think the structure you have drawn is what you represent it to be.
4. Where does meiosis occur in this life cycle?
5. How do you know?
6. Where does karyogamy occur in this life cycle?
7. How do you know?
8. Given stages in the *Coleochaete* life cycle, which are identified by letters A to F beside as many microscopes, arrange these letters in a proper sequence to represent a consecutive life cycle.

The Discussion—The purpose of a discussion is to think and to talk as well as one can. This thinking and talking should not take the form of a "lecturette" or of a recitation, neither should it be a drill nor an exercise. It should not be these things because memorizing and parroting someone else's remarks, or making neat responses, does not involve much thinking and hence does not achieve much learning. It should also be kept in mind that there are better ways of answering a question than by giving the student the answer. Finally, it should be observed that the more the discussion leader talks, the less time his students have to talk and, presumably, think. The less they think, the less they learn.

Questioning is an art, a difficult art. It is also a science. If the subject under discussion is to be examined in a critical fashion, the questioning has to be critical. The "question-and-answer technique"—if it means a more or less catch-as-catch-can series of questions, raised by either the students or instructor—has little merit. Nondirective techniques in unskilled hands can all too easily result in street-corner conversations. One is, accordingly, brought to a kind of discussion that is ordered and looks to the resolution of a problem. While it is presumptive to call it Socratic, this at least provides a model and a challenge.

While the original question or questions may cause only one mind to light up, its incandescence often excites and then ignites others. In a Socratic "dialogue" the questions raised and the statements made in answer to them are usually short; so the discussion tends to be smartly paced. It is often difficult, however, to adequately develop and complete a discussion in an hour's time. Rather than to rush the discussion, the generalization that one is unable to reach or develop in a first meeting should be held over.

The liveliest discussions are often those in which the students discover the inadequacy of a generalization or hypothesis to which they were originally attracted. By being alert to the unexpected twist that students give a discussion—to the original, even the irrelevant comment—a teacher can guide without leading. The teacher does not even have to expose the contradictions in, or the inadequacies of, the students' arguments because they are quite capable of doing this themselves. Should the teacher overplay his role, the corrective is ready at hand, for good students resent and resist too much teacher direction. To resist, however, they must supply an alternative; and this, of course, involves them still further, not only in the discussion but also in the course.

The leader who uses a Socratic approach does not abdicate. While considerable store is set by free discussion or undirected teaching in some problem-oriented courses, there is a growing awareness that the teacher has a responsibility for not only the selection of the subject but also the quality of the discussion that results.

In general, the good discussion leader begins his questioning with references to materials and ideas with which the students have some familiarity. To do this he must inform himself about what his students know and what they do not know.

The possibility that some students may get lost at the first turn of the discussion and so be unable to profit from the rest of the conference is real. Provision should accordingly be made for those who are unable to follow the argument. One solution is to invite such students to other conferences. After a second or a third conference, they should be able to follow the discussion to its conclusion.

A good discussion leader develops a sensitive ear for the unique contribution. Even the one with little virtue in itself can often be rephrased and used. The leader should be even more attentive to the substantial and original contribution, and should welcome it with obvious appreciation. He has a real ally in the student who resists the direction taken by the discussion. If he can get this student to challenge the logic of the class—even his own logic—it has been made clear that the student's role is important. If he can encourage the students to develop alternative hypotheses, or get them to discover the inadequacies of an hypothesis to which the class has been attracted, he will increase his effectiveness. He need not and should not be obtrusive. While the responsibility for the *strategy* of the discussion is his, he can afford to leave its development, or *tactics,* to the students.

There is, of course, no one right way to achieve a good discussion. The reason for employing Socratic, case, or problem methods is simply that the learning they engender is "self-arousable" (Gagné). While the uninitiated find it difficult to achieve such discussions, they can, with practice, become quite adept. The preparation made by the discussion leader often has as much bearing upon the success of his conferences as anything he does in them. First of all, the discussion should be anticipated in the lecture, the laboratory, and in out-of-class study so that the student has enough information and skills to do what is required of him.

The instructor has another kind of preparation to make. He should try to estimate how the problem appears to the students. He should try to identify the associations they can make and those analyses that should be possible to them. With his opening questions, he can usually determine how accurate his estimate has been, and raise or lower his sights accordingly.

For a more detailed treatment of the problems met in leading a discussion, and for a demonstration of discussions that utilized some of the Gagné-Tyler-McKeachie conditions, the following edited transcript is included. This is a transcript of an article, "The Dialogue," in *Improving College and University Teaching* in the Summer 1958 issue.

Conference-Discussion-Dialogue:
How Does an Apple Tree Happen?

When does an apple tree start happening? We have all heard the old saying that great oaks from little acorns grow. We all know what an acorn is, or think we do.

The clear inference, while not entirely correct, is that oaks begin as acorns. But does an oak or apple tree really start happening with the germination of the seed?

"No. A seed has a history; the embryonic apple tree in the seed has a history; as a matter of fact, the apple tree is well on its way to happening in the seed."[6]

Since embryos have a history, the apple tree must have a history that antedates seed germination. When does the embryo begin to happen?

"In the zygote or fertilized egg."

But the zygote by its very name suggests that it has a history; there has to be a "yoking" of something. What is it?

"A yoking or fusion of male and female gametes."

But did the apple tree begin to happen with these gametes? One might begin one's account here, but it would be a little odd, and scarcely decent, to leave these gametes hanging in the air. Where, in an apple tree, would you locate a female gamete?

"In an embryo sac."

And where do embryo sacs come from?

"I don't know where they come from, but embryo sacs can be traced back to megaspores."

Perhaps, then, an apple tree begins to happen with the germination of these spore. Where do male gametes come from?

"They are found in pollen tubes; pollen tubes come from pollen grains; and pollen grains can be traced back to microspores."

There are *spores,* then, in this, the male line. Where and when do apple trees begin to happen? Not with seed germination, not with the zygote, not with the gametes. It might be . . .?

"In spores."

An apple tree has spores? Let us stop here for a minute and write some notes to ourselves, so that we can eventually use these instructions as an artist might to piece together the picture of an ancestor of the apple tree that might be found among the first land plants.

Our first note: "The ancestors of apple trees must have possessed spores." But spores germinate to produce . . .?

"A thallus of some sort."

And what is a thallus? You don't know? Well, an apple tree, as you know it, is a cormus. What is the difference between a *cormus* and a *thallus?*

"An apple tree, a cormus, has stems, roots, and leaves; the thallus of a liverwort, or of a fern, or of an apple tree lacks stems, roots, and leaves."

If the thallus of anthoceros is large enough to be seen without a microscope, and some thalli may be as big as dinner plates, we can conclude that the thallus of the ancestral plant was probably microscopic in size, perhaps three to four inches in diameter. Let us add this note.

This brings us to a point where we have to ask some really embarrassing questions about the embryo sac. Why do you suppose it has synergids? These two cells serve no function today; they stand beside and arch over the egg, but the egg does not need attendants. After fertilization these synergids break down and disappear. Why do you suppose an embryo sac has synergids? You should be used to this sort of question now.

"Because apple trees have genes for synergids."

And why do they have genes for synergids?

"Because some ancestor supplied them."

[6] Student responses are italicized.

Some ancestor of the apple tree like the distant ancestor we are trying to reconstruct? What is a synergid, really? We may get some help in this if we study one of the thalli we have been talking about, the thallus of a liverwort, and elaborate on it. (We go to the blackboard.) Embedded in this thallus is a curious flask-shaped structure with a female gamete nestling in its base. What would you call this structure? If the suffix "angium" means "covering," what would you call it?

"It must be a female gametangium."

Yes, this female gamete is enclosed in, or surrounded by, a female gametangium. In the apple tree the synergids stand on either side of the female gamete and arch over it. It would be permissible, then, to suggest that perhaps the synergids represent a reduced or vestigial . . . what?

"Female gametangium."

Since synergids may be the reduced equivalents of female gametangia, a primitive ancestor of the apple tree may well have had, not synergids, but female gametangia. Let us add another note—"Draw a female gametangium."

Now what about the antipodals? You have memorized their name, but is that all there is to it? If we put antipodals through the "developer" we have used before, the theory of recapitulation, it may give us another clue as to the nature of the ancestral apple tree we are trying to deduce. Apple trees have antipodals; they have genes for them—and they got these genes from some ancestor, perhaps the one we are constructing. But are we necessarily going to draw antipodals in our ancestral plant as three small cells? Before answering this question we should perhaps ask what they could conceivably represent. When the anthoceros spore germinated it formed a thallus, and imbedded in that thallus were female gametangia. We have suggested that we should draw a female gametangium, but are we going to leave that gametangium dangling in the air? If the megaspore germinates to form an egg and synergids, it presumably also forms antipodals; and if the synergids represent a vestigial female gametangium, what is there left for antipodals to be but . . .? You don't know?

Well, in the liverwort, what did the spore form besides a female gametangium and an egg? What is the tissue in which the gametangia are found? What do you suppose antipodals really are?

"The thallus?"

Yes, they would appear to be reduced or vestigial thalli. We are now able to write another note, "Draw a thallus." If antipodals represent the vestigial thallus of some primitive plant, this thallus presumably should be larger than three cells. Why?

"Vestigial structures, by their very name, are smaller than the original structure."

Perhaps you are a little tired of thinking and would like to draw. So let us go back to the seashore reaching out of that prehistoric sea and draw an ancestral apple tree, following our own directions. It had to have a *spore;* let us draw one. This spore presumably germinated to form a *thallus;* and we were told ourselves to draw a thallus two or three inches long. And there should be, we have said, a female gametangium. Let us draw one. But where shall we put it? Imbed it if you wish.

As you stand off and admire your work, you say this does not look much like an apple tree. It doesn't but let us push on and see what we can discover. What is the generation represented in this primitive plant in which a spore has germinated to form a thallus and gametangia? You don't know? Well, what is the generation represented in the life cycle of the apple tree that begins with a megaspore or microspore and ends with an embryo sac or a pollen grain, with a female gametangium or a male gametangium?

It's the haploid generation."

Most of an apple tree as you know it is diploid, or stated somewhat more accurately, the thing you have taken to be an apple tree is diploid. Does this plant, this generation, have no history? What about the above-ground part, the shoot? Are we going to write a note to ourselves—"Draw a shoot?" If we do, someone is going to ask, "What is a shoot?" What is it?

"The stem and leaves."

But whoever has to draw our theoretical plant is almost certain to ask: "What kind of leaves shall I draw—leaves like pine needles or like apple tree leaves?" Let's not be too quick with our answers. If ontogeny should repeat phylogeny and you take into account the ontogenetic development of apple leaves, what would it have to be? Leaves are formed on a stem-growing point; where cylindrical, bent fingers develop; and only in the later stages do the flat, broad blades appear. Before we had a leaf, or at least before we had anything we would recognize as a leaf, what did we have?

"We had a leaf rudiment, a cylindrical leaf rudiment."

What does a cylindrical structure suggest to you?

"A stem."

In other words, we have a stem-like structure before we have a leaf-like structure. And if ontogeny repeats phylogeny, what might this suggest? It does not prove it, but what does it suggest?

"That perhaps we had stems before we had leaves."

A note for the artist! "Draw a shoot, but remember, no leaves." "But," our artist is almost certain to ask, "What kind of stem do you want? One with a single, unbranched trunk like a palm, or something that branches like an apple tree?" For an answer let us see why we left a question mark standing by the seedling we drew earlier. How does a morning glory seedling get on with the business of forming leaves? The diagrams are on the board. First it produces a horseshoe-shaped leaf, and only later does the oval, pointed leaf that we associate with the morning glory appear. You say, "What bearing does this have on the development of stems? On leaves?" If we had stems before we had leaves, what are leaves?

"Modified stems."

If leaves are modified stems and if we read the ontogeny of morning glory leaves backwards, we observe that the venation or veining of the leaves is dichotomous in the first leaves, monopodial in the later or foilage leaves. What does this suggest as regards the branching of the stem we have to draw. If leaves are modified stems and the venation is dichotomous before it is monopodial, what suggestion would you make to the artist?

"Make the branching dichotomous."

But where are we going to attach this stem to the theoretical plant on the board? For an answer let us review our understanding of the ontogeny of apple trees. The apple tree has its origin in the seedling, the seedling in an embryo, the embryo in a zygote or fertilized egg. Now where do we find these eggs?

"In female gametangia."

Where, then, shall we attach this stem?

"It must grow out of the female gametangium."

You have no way of knowing it, but you are well on your way to discovering how an apple tree happens.

Let us complete our drawing and then compare our theoretical plant with some actual fossil plants believed to be the first land plants. Here is a picture of a Silurian landscape and here are our plants.

"Well, I'll be . . ."

The Examination—The examination at the end of a course, like the tail of a dog, can, and often does, "wag" the course. Certainly for students it is very likely to determine the kind of course that is learned.

While the teacher is usually, and rightly, held accountable for his examinations, his is not always the exclusive responsibility. Sharing the responsibility for many examinations is the institutional grading system. Where this system defines grades in percentages—an A equals 95 to 100 percent, a B equals 85 to 95 percent, and so forth—the faculty and administration have a hand in writing every examination because the teacher is, to all intents and purposes, forced to write examinations in which some 5 to 10 percent of his students can score from 95 to 100 percent on the course and 15 to 20 percent can earn grades of 85 to 95 percent. With such regulations on the books, what does any smart or, for that matter, any conscientious instructor do? He asks questions that 5 to 10 percent of his students can answer with great accuracy and completeness, and that some 15 to 20 percent can answer well enough to miss perfection by no more than 15 percent. Since he cannot risk many really searching questions, the only sensible—and certainly the safest—thing to do is to ask questions on material that can be memorized.

An examination that emphasizes memory is not likely to be challenged by students because they have been memorizing for 12 or more years, have become addicted to it, and see in it their best guarantee of a good grade. Furthermore, were the students to insist upon conformity with the institutional grading system, the administration would have little choice but to enforce it. To expect teachers to endorse practices that raise questions about their own examinations is to expect too much. When you add to these considerations the fact that the memory-emphasis examination is easy to write and is often "objective" —and hence easy to defend—it is rather evident why these examinations are so popular. Finally, teachers, and particularly teachers of lower division courses, are likely to tell you with more truth than ill-grace that their teaching loads do not permit the writing or grading of examinations that reflect a concern for critical thinking and ideas. Then, too, of course, one must protect his time for research. He is naive if he does otherwise.

A memory-emphasis examination, or any examination that does not teach, misses a wonderful opportunity. Actually there are few opportunities as good as the examination for acquiring an overview of a course. An examination that teaches can also be used to help the student and teacher evaluate their performance.

If the examination is used as a teaching device, it should not be a surprise. If the class has been thinking and talking about important things and the examination deals with them, it will not be a surprise. If, in other meetings of the course, critical methods have been employed, the students should not be surprised if they are asked to employ these methods in an examination.

When at the beginning of a course the instructor states that apart from everything else it is his hope that the class will acquire an "understanding of the principles," a literal-minded student is very likely to assume that the examinations will test his understanding of principles above all else. When he discovers that all that is required is a good vocabulary, a word in this blank, or a check in that bracket, he may lose respect for the examination and its author.

An essay-type question, particularly in the sciences, is a rare experience for teacher and student. It would be helpful if it were not so unique because students will often make the right response in the first sentence, only to demonstrate in the next that they really do not know what they are talking about, that the material just has not been taught or learned. While this discovery is painful for both teacher and student, it is the beginning of wisdom.

One of the awkward things about writing a good examination is that it is impossible to do so unless the instructor has done some hard thinking about his course. The sample, edited examinations provided below are described at greater length in *Improving College and University Teaching*, Autumn 1958 issue, under the title "The Examination."

I. The Fine Points of Baseball: The Whole Animal

1. All too few baseball fans seem to know what is really happening when the clutch hitter digs in at the plate. First of all, they don't know what kind of muscles he is using to grasp the bat. In the space below, draw and label such a muscle fiber so that others may begin to learn some of the fine points of the game.

2. How has the mass of this muscle been increased since the days when the best the batter could swing was a rattle? Draw a cell below and show the result of free nuclear division. If a true cell divides, it divides by cell division. In accounting for the development of muscles we make certain assumptions. We say, for example, a striated muscle is noncellular. This brings us indirectly to a problem of definition: What is a cell? Explain what was wrong with the assumption called the Cell Theory, the theory that all living things are composed of cells or exist as single cells.

3. A batter grasps the bat with all five fingers of both hands. The forepaws of most mammals, the flipper of a whale, the wing of a bird, and the limbs of a lizard or a frog have five digits. According to the Taxonomic Theory, why do all of these animals possess five digits?

4. What is there about a man's hand that enables him to get a better grasp on the bat than these other animals could?

5. The whole business of batting is a matter of muscles pulling on bones. How, in one arm, can the batter have tissues as different as muscle and bone?

6. To the really discerning fan, there is a basic explanation for muscular contraction. What is the ultimate, ultramicroscopic explanation for the ability of a muscle fiber to contract?

7. Most fans don't even seem to know how the blow is delivered. The credit is usually given to "the wrist action," or to "the way the shoulders are put into it." But we know that it is *A.T.P.* that does the trick. What is A.T.P.? Where is A.T.P. found in the batter? What does A.T.P. do for the batter?

8. When he swings, what triggers the A.T.P. into action? Where does this substance come from?

9. How does the ballplayer "recharge" his muscles so that he can run to first base?

10. As he races toward first base, what parts of his body are *not* playing baseball? List them.

II. The Whole Plant

Since a lot of splendid, full-blown language has been used to explain what *understanding* is, we shall eschew the literary and see what we can do with a simple little game called "follow the dots."

Knowledge of a course may look like the diagram on the blackboard, a mass of seemingly unrelated, uninterpreted—and hence ununderstood—facts, represented graphically. You could memorize all these facts and objects, but you would not understand an apple tree. What you have to do is to relate them. But how does one do so? First, like a sorting machine, our brain has to pull out the relevant or related facts. Then by induction or deduction we have to interpret these facts. Your answers to questions 1 through 7 are your interpretations, your hypotheses.

1. (Join the dots X, 1, 2, 3)

One cannot appreciate what makes an apple seed a seed without comparing it with other seeds. A skunk cabbage seed is made up of endosperm and embryo but has no seed coat. A corn grain, with fruit coat removed, is composed of seed coat, much endosperm, and embryo; a pinion pine seed has a seed coat, gametophyte or thallus, and embryo.

a. What structure of an apple seed makes it the entity known as a seed?
b. Why did you make the choice you did above?

2. (Join the dots X, 4, 5, 6, and X, 7, 8)

The "brown dust" that falls from a fern sporangium is made up of spores. Seeds and spores germinate to form plants, but there is a fundamental difference in the immediate product of spore and seed germination. Check the correct answer below.

a. Spores germinate to produce a sporophyte ( ), gametophyte ( ).
b. Seeds germinate to produce a sporophyte ( ), gametophyte ( ).
c. How do you know in *a* above that the plant is a sporophyte or a gametophyte?
d. Now draw such a plant.
e. How do you know in *b* above that the plant is a sporophyte or a gametophyte?
f. Now draw such a plant.

3. (Join the dots X, 4, 5, 6, and X, 9, 10, and X, 11, 12)
From what you know about flowering plants or ferns, what would you deduce the food source for the developing embryo of conifer seeds to be?

4. (Join the dots X, 13, 14, 15, 16, and X, 17, 18, 19, 20)
One cannot really understand what a seed does for a plant unless one appreciates that a seed is the product of sexual reproduction and understands what sexual reproduction is and what sexual reproduction does for a plant.

a. What is the *proof* that sexual reproduction involves meiosis and karyogamy?
b. What is the biological or overall significance of sexual reproduction?

5. (Join the dots X, 23, 24, 25, 26, 27)
In the embryological development of a plant such as the apple tree, the zygote divides in a horizontal plane to form an embryo and a suspensor cell. Then the embryo cell divides in a horizontal plane to form a two-celled embryo, and these two cells in turn divide in horizontal planes to form a four-celled embryo. But now these four cells divide many times in vertical planes to form four multicellular initial layers. What determines the pattern of division in this small embryo? In other words, what determines when cells shall divide and how they shall divide?

6. Why do we think that the first living things were heterotrophic?

7. (Rejoin the dots 28, 29, 30, 31, 32)
The embryo in an apple seed is an apple tree in miniature, and apple trees are related:

a. to all angiosperms.
☐ What is the evidence of this relationship?
b. to all seed plants.
☐ What is the evidence of this relationship?
c. to all archegoniates.
☐ What is the evidence of this relationship?
d. to the blue-green algae.
☐ What is the evidence of this relationship?
e. to the *Amoeba*.
☐ What is the evidence of this relationship?
f. to *Rhynia*.
☐ What is the evidence of this relationship?

In the biology course to which reference has been made in the preceding pages:

1. The enrollment quadrupled even though it had the reputation of being a difficult course.
2. It was regularly audited by Ph.D. candidates in the biological and applied sciences even though it was an introductory course for nonmajors.
3. While it originally had the sympathetic support of but 4 of 20 of the biology faculty, this faculty, almost to a man, later urged

that it be made the introductory course required of majors. A contributing factor was the fact that, while originally for non-majors and while it enrolled but one-third as many students as the combined introductory courses in the professional sequence, is proved to be the best single source of majors.

4. The course was regularly audited by members of the faculty and outside visitors.
5. The content learned increased to the point where twice as much or more information was examined in the latter years than in the initial year.
6. The quality of the learning, as measured by the examinations, improved.
7. When the grades received in this course and in other introductory biology courses were plotted against the presumed potential of the students as measured by their IQ's and their previous academic record, the students in this course tended to realize their potential. In the other introductory courses, potential *A* students settled for *B's* and *C's*, and potential *C* students, by splendid feats of memorization, earned *A's*—this to a degree not met in the experimental course.
8. The students in this course spontaneously, and without the staff's knowledge, organized study groups in virtually every dormitory, sorority, and fraternity. These groups were led by upperclassmen who had taken and recommended the course to underclassmen.
9. The students organized the only intellectually oriented extra-curricular activity—discussion groups so numerous that it was difficult to provide enough lively and sufficiently interested faculty leaders.
10. Graduate students volunteered their services, sometimes without compensation, as assistants in the course.
11. Of 70 students in an English composition course who were asked by their instructors if they had had an intellectual experience on the campus, only 8 were aware of such an experience in a class. Of these, seven identified the "Bio Sci" course as the one in which it had occurred.[7]

[7] "Teaching an Integrated Course in the Biological Sciences," *Improving College and University Teaching*, May 1953, p. 3-11.

"The Socratic Method in Modern Dress," *Improving College and University Teaching*, Summer 1957, p. 60-63.

"Inquiry Into Inquiry," *Improving College and University Teaching*, Autumn 1957, p. 93-99.

A particularly interesting feature of this course was that the experimentation was total, not a series of exercises affecting only some part of the course. It involved all the elements discussed here—the lecture, the laboratory, the conference, the examination, and all the time spent in these meetings, including their preparation.

Second, the course was part of a professional sequence and content was not sacrificed. Actually, it was enhanced.

Third, the presentation, the grades, credits, even hours had to be fitted into traditional routines.

Fourth, the students were not academically talented or academically oriented in any special degree. They represented a relatively large cross-section of the students accepted in a land-grant college which, at the time, was accepting all graduates from approved high schools.

Conclusion

A CRITICAL PROBLEM FOR THE COLLEGE TEACHER—whether he realizes it or not—is what is he going to do about the most important part of his job, namely, the imparting of information. An equally critical problem for the administrator and student is how to make good teaching and good teachers go farther. About these related problems, one knows, first, that the teacher should extricate himself from simply transmitting information, and this as quickly and as completely as he can. He should do this because students can inform themselves, if they will, and do it as well without a teacher's personal intercession as with it.[8] If students will accept, or can be persuaded to accept, their responsibility for the acquisition of information, good teachers can be freed to *teach* rather than to *instruct* or *tell*.

But will students make this contribution to the staffing problem? The answer is that in many programs they have. The difficulty, where there is a difficulty, lies, apparently, more in the reluctance of teachers to abandon their roles as transmitters of information than it does upon the students' willingness to accept a new role. Where students have been given an opportunity for solid and sophisticated independent study, they have usually grasped it with an enthusiasm that surprised their teachers, whose defense of their informing role had been that they did it because their students would not inform themselves.

In involving students in independent study there is, apparently, a right and a wrong time, a right and a wrong way. The right time is the first course in which they enroll at the university; the right way is to be very matter of fact about it, to take them into the new program without fanfare or announcement. When begun in the junior year, independent study programs have been disappointing because the students had become so spoiled by spoonfeeding that they could not be persuaded to do with good grace what freshmen did, and did well, without persuasion.[9] This is all very disconcerting because it suggests that the longer students associate with some teachers, the more de-

[8] Hatch, op. cit.; Parsons, op. cit.; and Pfnister, op. cit.

[9] Samuel Baskin and Ruth Churchill, "Experiment on Independent Study, 1956-1960." Yellow Springs, Ohio: Antioch College.

pendent they become. Why then do teachers insist on wasting their time and that of their students making themselves more and more expendable in the process? Before attempting to answer this question, let us see what is involved when teachers *teach* rather than *tell*.

According to the consensus examined in this publication, good teaching involves active learning, a learning that is characterized by discovery or guided discovery, enquiry or inquiry, or in somewhat more prosaic language, teaching that is problem-oriented. Such teaching obviously makes heavy demands upon a teacher's scholarship. It is, accordingly, no accident that those teachers who are most at home with it are typically scholar-teachers whose weight is well distributed on both sides of the hyphen. The support of this consensus is impressive because besides Gagné, McKeachie, and Tyler stand Bruner and many others who have been doing research on institutional impact, institutional indices, and the attributes of highly productive institutions. Those doing research on personality development and the noncognitive aspects of learning are also included here. A bibliography on much of this research is to be found in *The American College: A Psychological and Social Interpretation of the Higher Learning.*[10]

While some of the research referred to above has been done in schools of education, the bulk of it, interestingly enough, has been done by anthropologists, sociologists, and psychologists. Even political scientists and *bona fide* philosophers have gotten into the act. Even more interesting is the way the scientists have discovered for themselves, and convinced themselves, that there is merit in teaching and learning featuring inquiry—or enquiry, as they prefer to spell it.

Finally there are developments, all quite substantial, such as independent study (including honors), study abroad, work-study, administrative and faculty permissiveness, curricular flexibility, and flexible progression that support the case for inquiry. For what is the essence of independent study (and honors), for example, if not inquiry? Permissiveness and flexibility similarly are logical and necessary concomitants to inquiry; for if students are locked in a system in which they must serve time irrespective of the quantity and quality of their efforts, they can hardly be persuaded to make the efforts required in inquiry.

The end and means of teaching and a solution for certain of our most vexing educational problems appear to lie in inquiry.

[10] *The American College: A Psychological and Social Interpretation of the Higher Learning,* Nevitt Sanford, ed. New York: John Wiley & Sons, Inc., 1962, 1,084 p.

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